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PROSPECTS FOR THE UTILIZATION OF WIND ENERGY IN CZECHOSLOVAKIA

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16. Abstract The paper investigates the technical and economical conditions for the utilization of airstreams in Czechoslovakia. The probable mean wind velocities in various districts of the country, their number and the probable daily and yearly charts at various altitudes, the most windy districts, the possibilities and extent of utilizing the airstreams by power stations equipped with prime movers with a 50 m propeller diameter and a 30-35 m high tower are investigated and presented on the basis of many years of observation by the State Meteorological Institute. The author determined that the power stations in Czechoslovakia should have a maximum output of 500 kW and a yearly production of about 700,000 to 800,000 kWh, so that 1000 such stations could replace the power plant in Ervenice. The author calculates the probable cost per kWh generated in the wind power plant on the basis of the proposed estimate for the capital investment and evaluates the economical results based on this solution, which are not practical in the near future.

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PROSPECTS FOR THE UTILIZATION OF WIND ENERGY IN CZECHOSLOVAKIA

F. Šembera

The world coal and oil resources, which so far have been the /477* main source of energy are being rapidly depleted, and the price of these two minerals which are the basic raw material for the chemical production of hydrocarbon derivatives which are used on an ever increasing scale and are becoming more and more important is rising continuously. These circumstances lead to deliberations that emphasize more and more the infeasibility of burning high quality coal and oil in boilers and in household and industrial heaters in which only a fraction of the energy from the coal and oil is used up due to the low efficiency and, in addition, valuable substances are lost in the gas products and ashes which escape into the air or form considerable waste whose removal and transportation causes additional problems. We are beginning to realize that we can burn, at most, selected waste which cannot be processed in any other way and transported to remote consumption areas where refined electrical energy, heat energy and energy contained in one coal derivative, city gas or other related gases (gas from coke plants, blast furnaces, the soil, etc.) can be supplied more cheaply and effectively.

Mankind is looking for other energy sources, among which /478 atomic energy is the source of agitation and political tensions in the world and at the same time the source of intensive research looking for ways to obtain it economically from uranium and its derivatives. The decay and destruction of atoms will undoubtedly be the most powerful main energy source in the future, its production and conversion into other useful forms, however, will still require a considerable development period which cannot be estimated well due to the secrecy surrounding all research studies and

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*Numbers in the margin indicate pagination in the foreign text.

methodological procedures for military reasons. However, other known sources that have been used earlier to which we return again in order to take advantage of them more economically and better than until now also exist. These are primarily water energy and the energy of flowing air which is considerable, and if we were able to use it better, it could replace the entire energy obtained until now from coal. Basically the origin of these energies is the same as that of the energy from coal, i.e. solar radiation. The numbers furnished by the Swedish physicist Arhenius in this respect are remarkable. He estimates that the energy absorbed by the ground in 1 year (including that in the atmosphere) from solar radiation is $1330 \cdot 10^{18}$ kcal, and without the atmosphere $530 \cdot 10^{18}$ kcal, the energy contained in the coal deposits in the ground to be $44 \cdot 10^{18}$ kcal, and in the oil deposits $0.1 \cdot 10^{18}$ kcal. The energy accumulated in water drops in clouds is, according to the same author, $28 \cdot 10^{18}$ kcal per year, the energy of flowing water $0.055 \cdot 10^{18}$ kcal per year, and the energy of streams $33 \cdot 10^{18}$ kcal per year. This energy is continually replenished and by drawing it off and converting to our advantage, it will not be depleted like the coal deposits, but will be supplied for many millenia by the sun. The total amount of energy from the coal consumed throughout the globe in 1 year is estimated by Arhenius as $0.0072 \cdot 10^{18}$ kcal. A comparison of the figures that were given is of great interest. We see from them that the yearly energy of flowing water is 0.055/0.0072, i.e. it is 7.6 times greater, and the yearly wind energy is 33/0.0072, i.e. 4600 times greater than the yearly energy obtained from coal mining.

It seems inconceivable that such a minute amount of water and wind energy has been used until now, which leads to the idea that something is being ignored and that much more attention should be given to the use of water and wind energy. However the point is not only the magnitude of the resources but also their economical use. With regard to our Republic, the problem of water energy has been

studied thoroughly on many occasions and many publications give the guidelines for the greatest possible intensive development of /479
water resources that can be built in our country at a reasonable cost with considerable advantage. We are not a country that is rich in water power, and only the rivers Vltava, Labe, Vah and the Danube represent the major sources of energy. The remaining rivers can only provide small sources whose significance is local.

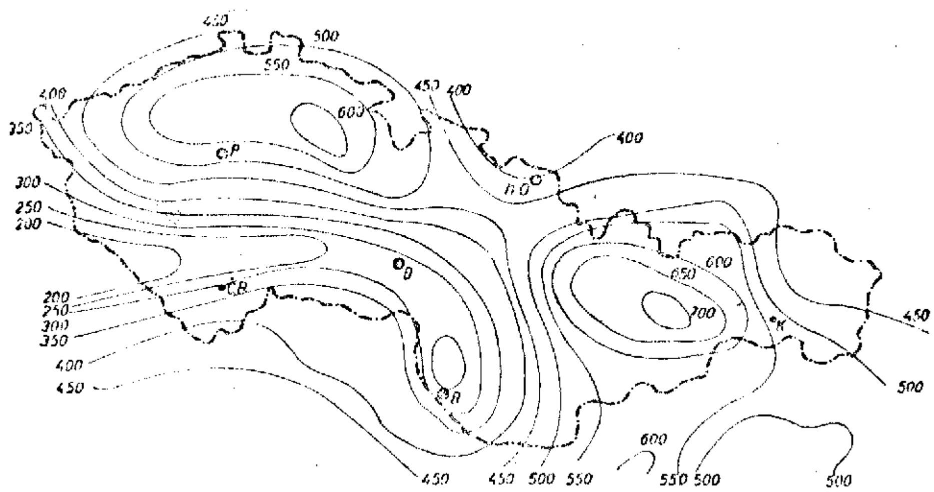

Fig. 1. No wind and weak winds (0-1° Beaufort). January.

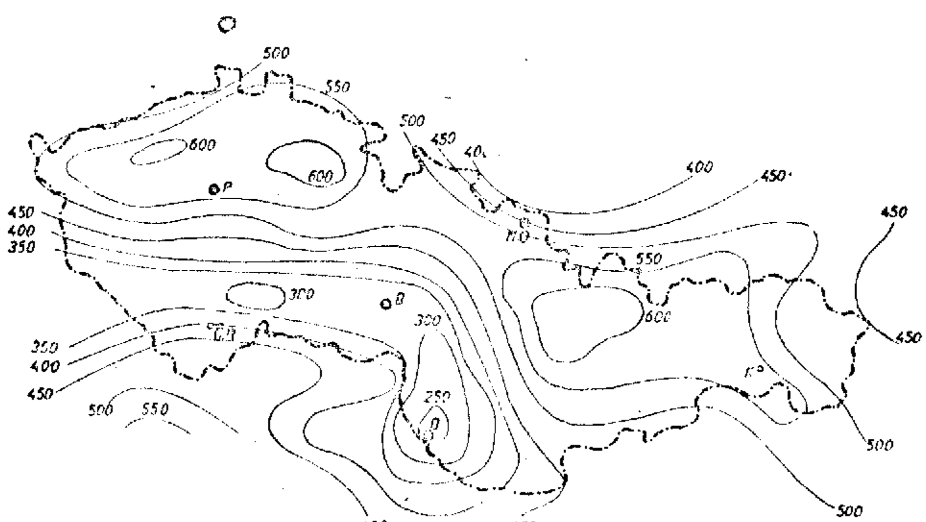

Fig. 2. No wind and weak winds (0-1° Beaufort). July.

The possibilities of taking advantage of wind energy which are being proposed from various quarters and publicized with considerable optimism must also be studied. In some countries experiments have been made recently on a relatively large scale and we would like to know whether a practical solution can also be obtained in our country. The purpose of this study is to furnish a brief review of the technical and economic conditions for taking advantage of wind energy that exist in our Republic.

Before we can investigate these conditions, we must first know the character and quality of the airstreams on the territory of our state and then evaluate the methods and means that can be used advantageously in our conditions. At the same time the magnitude of the energy quanta that can be obtained must also be evaluated as well as whether these can be obtained by other methods more efficiently and economically. The observations made by the State Meteorological Institute (SMI) over many years can be used for the first task even though they are not complete from the power engineering standpoint and do not provide complete answers to the problems which the air mechanics engineer and designer of air-operated engines must solve. Nevertheless, they provide a general idea about the course of the wind, its duration and various velocities of the wind in different regions in our state. The weather in our Republic has a continental character, since the distance from all seas is relatively large. Therefore regular seashore winds which are formed during the day by the nonuniform heating and cooling of air layers above the land and the sea do not occur here. The northern tradewinds that are formed through the nonuniform heating of air at different geographic latitudes are partially subdued in our country by the mountain range which extends almost along the entire northern boundary of the Republic. In the south, at least in Bohemia and also partly in Moravia, the effect of the Alp bulwark is felt. The mountainous inland territory in Slovakia has very different wind conditions in the mountain r i d g e s and in the valleys between them.

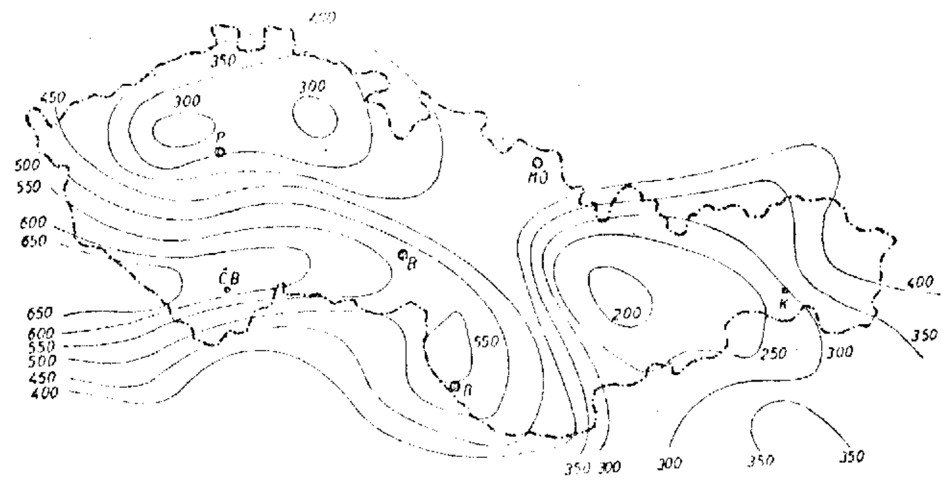

Fig. 3. Moderate and fresh winds (2-4° Beaufort). January.

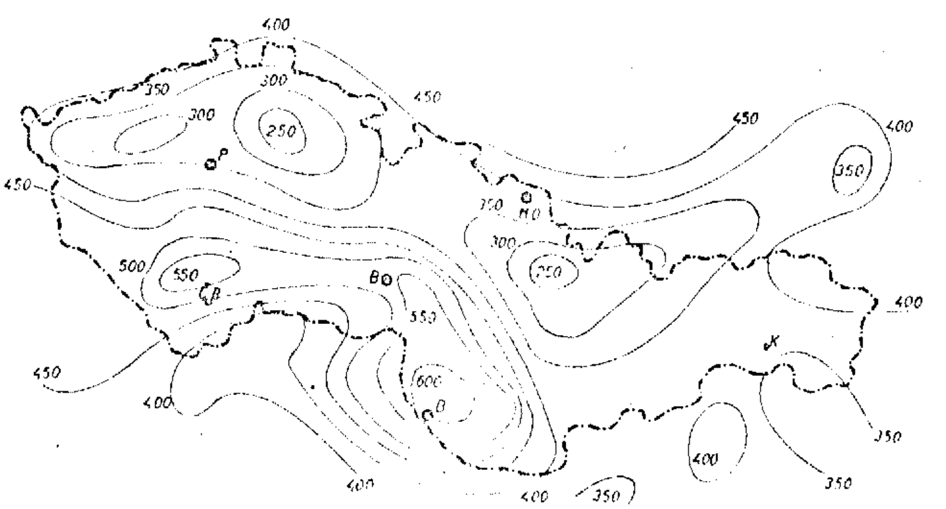

Fig. 4. Moderate and fresh winds (2-4° Beaufort). July.

The constant observations of the force of the wind by the State Meteorological Institute confirm that the average velocities that were observed over 10 years characterize quite correctly the general wind conditions in the country and that the deviations from these averages are exceptions that can be ignored in considerations attempting to take advantage of wind energy. The following data must be known in various regions of the country to enable us to determine where the wind power stations or engines must be constructed: /480

a) The velocity of the wind at different times of the year and the changes in the velocity in 24 hours as well as the changes at various altitudes above ground.

b) The location of the regions that are most favorable from the standpoint of wind conditions and the production and supply standpoint for the building of engines.

c) The duration of different velocities during the day and during the year (the frequency of the velocities).

d) The impact force of the wind and the frost conditions in the air considered for the supply sources.

The direction of the wind and its changes do not matter very much provided they are not very frequent and sudden, since wind engines are built in such a way that their position adjusts itself automatically or with the aid of accessory devices to the direction of the wind.

The Defant curves reproduced from the archives of the State Meteorological Institute given in Figs. 1-6 will be adequate for a general orientation and evaluation of the wind conditions in the Republic. They are based on 10 years of observations carried out in the years 1896-1905 or 1900-1909 and they express the frequency of the wind velocity in Beaufort numbers. The tables plotted in Figs. 1 and 2 give winds, number 0-1 (velocity 0-1.7 m/sec), the tables plotted in Figs. 3 and 4 the winds number 2-4 (velocity 1.8-7.4 m/sec)

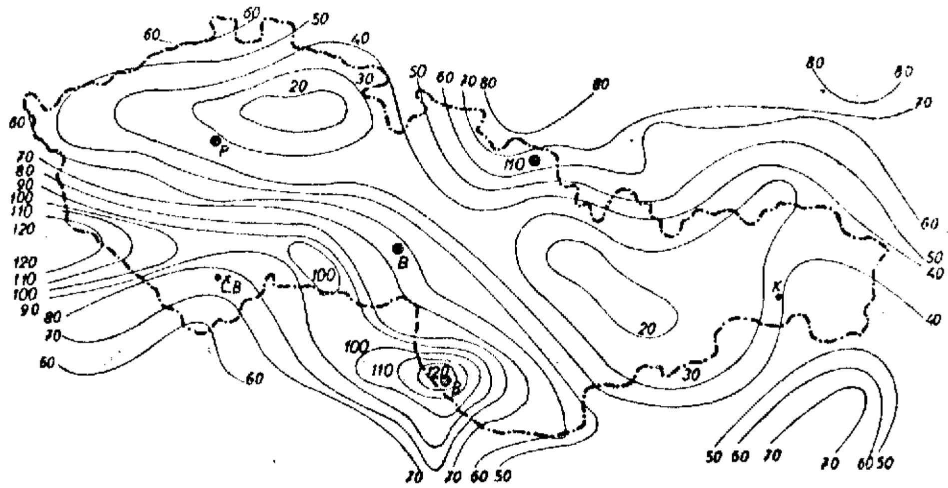

Fig. 5. Strong and turbulent winds ($\geq 5°$ Beaufort). January.

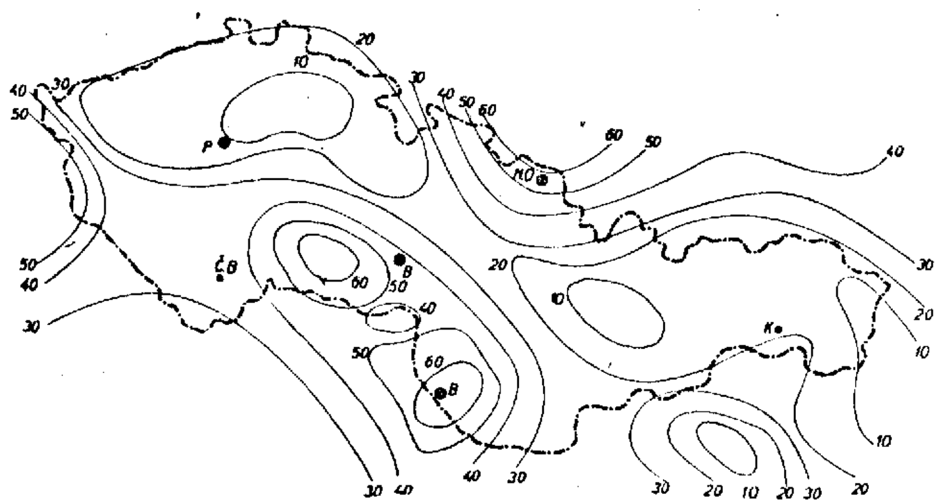

Fig. 6. Strong and turbulent winds ($\geq 5°$ Beaufort). July.

and the tables plotted in Figs.5 and 6 winds number 5 and greater (from 7.5 m/sec and above). The more recent observations of the SMI that go back to the period of our Republic have not yet been processed systematically, and it will be necessary to compare them with the Defant curves in the future. The SMI carries out the observations three times daily, at 7 a.m., 1 p.m. and 9 p.m. In the

10 years that were mentioned this amounts to $3 \times 31 \times 10 = 930$ observations in each month and the numbers associated with the reproduced curves denote the number of times that a wind of a given force was observed at a certain point of the curve during these 930 observations. Thus we can read from Fig. 1 that there was no wind or a gentle breeze with a maximum velocity 1.7 m/sec in January in 550 cases out of the 930 observed cases, and only 30 strong and turbulent winds (Fig. 5) out of the 930 winds observed in 10 years. We read from Fig. 2 that there was no wind in July in Bratislava approximately in 270 cases out of the 930 observed cases and that there were strong and turbulent winds in July (Fig. 6) in 60 cases out of the 930 cases in the 10 years. At the same time the curves show which localities on the territory of the Republic have in January or July the same wind conditions, which are the most windy regions, and on the contrary, which regions have most frequently no wind. By a more detailed analysis of the curves we can determine that medium and strong winds occur most frequently around Bratislava, and that the stillest region in the Republic is the vicinity of Poprad below the Tatra Mountains (protected from the north and south by mountains. Obviously on mountain ridges and isolated peaks the conditions are different and they must be studied or measured separately. Table I gives the characteristic regions according to these curves in sequence. The table was set up in such a way that the number of observed cases where there was no wind, the number of moderate and fresh winds, as well as strong and turbulent winds in January and July was read off from the Defant curves, and the cases in which a wind with a velocity greater than 1.7 m/sec was determined were added. The last column of the table gives the number of times in which a wind above 1.7 m/sec was determined in January and July (together) during $2 \times 930 = 1860$ observations. We see that Prague had 740 cases in which a wind above 1.7 m/sec was determined, however Bratislava had 1330 cases. While in January in Prague in the 10 years, out of the 930 observed cases there were only 30 cases with a wind above 7.4 m/sec, there were 120 such cases in the same period in Bratislava. /481

TABLE I. WEATHER IN REGIONS IN CZECHOSLOVAKIA ACCORDING TO DEFANT CURVES.

Sequence	Region	Wind up to 1.7 m/sec			Wind 1.8-7.4 m/sec			Wind above 7.5 m/sec			Total Out of 1860 Observed Above 1.7 m/sec
		Jan	July	Total	Jan	July	Total	Jan	July	Total	
1	Bratislava	260	270	530	550	600	1150	120	60	180	1330
2	Klatovy	180	390	570	650	500	1150	100	40	140	1290
3	Tábor	240	340	580	600	550	1150	90	40	130	1280
4	Jihlava	230	380	610	600	500	1100	100	50	150	1250
5	Brno	320	340	660	550	550	1100	60	40	100	1200
6	Trenčin	370	340	710	500	550	1050	60	40	100	1150
7	Štěchovice	370	450	820	500	450	950	60	30	90	1040
8	Ostrava	410	470	880	450	400	850	70	60	130	980
9	Duchcov	530	510	1040	350	400	750	50	20	70	820
10	Prague	550	570	1120	350	350	700	30	10	40	740
11	Turnov	560	570	1130	350	330	680	40	10	50	730
12	Poprad	540	610	1150	300	250	550	30	20	50	600

These facts are very interesting, and although their accuracy is not reliable, their order of magnitude is satisfactory, and therefore they need only be verified on the basis of more recent observations. Since the force of the wind also is often given in terms of the velocities in km/h, especially during windstorms, I also present a comparison in Beaufort numbers and velocities per minute or hour.

Beaufort number	0-1	2-4	5-12
Designation of wind	No wind to gentle wind	Moderate to fresh wind	Strong wind to hurricane
Velocity in m/sec	0-1.7	1.8-7.4	above 7.5
Velocity in km/hour	0-6	7.0-26	above 27

A powerful windstorm which knocks down pedestrians and causes great damage to forests and buildings is denoted by Beaufort number 11 and its velocity is usually 25-29 m/sec, i.e. 91-104 km/hour. With regard to the Beaufort curves and the table based on them, it should be mentioned that they are based on individual observations and evaluation of the wind by layman observers in a large number of meteorological stations. Actual measurements and velocity records with the aid of anemometers have so far been obtained only in a few stations (Prague-Karlov, Petřín, Milešovka, Brno, Bratislava, and Lomnický štít in the Tatra Mountains). Therefore all data obtained from the curves are only preliminary. Experience and more accurate anemometer measurements tell us that in one place, the velocity of the wind differs considerably at different altitudes and positions in the terrain. Thus the average yearly wind velocity at the Prague-Karlov station is about 3 m/sec, whereas at the Petřín observatory tower it is 6 m/sec. The maximum velocities are 3-5 times as high and even higher in very exceptional cases. The highest velocities measured in Petřín are about 35 m/sec.

The dependence of the velocity and steadiness of the wind on the altitude above the terrain is a very important factor which must be examined in greater detail.

The measurements in our country and abroad determined that the dependence of the velocity of the wind on the altitude above the terrain obeys a certain law, which different authors describe by formulas which give very similar results. Hrudička gives for the average yearly wind velocity in our regions two formulas:

For winds near the ground $v_0 = 0.7\sqrt[3]{H}$ m/sec,

For winds at higher altitudes in free space (undeveloped areas)

$$v = 1.6\sqrt[3]{H} \text{ m/sec.}$$

In these formulas v_0 is the mean yearly velocity and H the altitude above the terrain.

From the second formula we obtain

for H	5	10	20	30	40	50	60	100 m
v	2.7	3.5	4.3	5.0	5.5	5.9	6.3	7.5 m/sec

All this agrees well for example with the observations made at the Petřín observation tower which is 60 m high where the yearly averages were about 6 m/sec. For power engineering purposes, we must also know how the velocity of the wind changes during the day, since the load on power stations fluctuates considerably and it is necessary to determine how the outputs of wind power stations will fit into the energy consumption diagram. Also in this regard the conditions vary considerably with the altitude above ground,and the measurements carried out in Eilwese in Germany in June,1916, whose results are reproduced in Fig. 7 according to Koeppen and Hellmann,are very instructive. We see from them that near the ground at an altitude of 2 m,the velocity rose from midnight from 2 m without great fluctuations until the noon hours to as much as 4 m/sec,and then dropped again with very small fluctuations until the midnight hours. However, already at an altitude of 16.5 m the picture is different: the velocity is the same for 24 hours and it only fluctuates in the range 3.5-4.5 m/sec. The moderate /482 maximum occurs again at noon. At an altitude of 42 m the behavior is the opposite of that near the ground. The maximum velocity occurs in the night hours (up to 5.5 m/sec), the minima occur around 9 a.m. and 5 p.m. (3.5 m/sec at 9 a.m.) and the rise is greater during the noon hours. At a still greater altitude, at 82 m, the characteristic behavior that was described is even more pronounced, the night maximum exceeds considerably the noon peak (7 m/sec compared to 5 m/sec). These conditions also prevail at different altitudes above ground, as well as in other areas, and it is evident from them that with regard to the energy consumption curve, the flows in the lower layers in which the velocity maxima predominate in the day hours are more advantageous. The fact that on the boundary between the layers that had the two characteristics that were described; sudden changes in the direction and force of the wind occur which are adverse or possibly even dangerous for wind engines is also important. Therefore a certain amount of caution must be exercised when the height of the towers for wind power stations is selected. We must keep in mind that although the average wind velocity which can be utilized increases with the height of the tower, the velocity maxima at greater altitudes occur at night, and that possibly there may also be layers in which the winds have high impact forces and possibly dangerous vortices. In this regard more detailed and accurate measurements will have to be

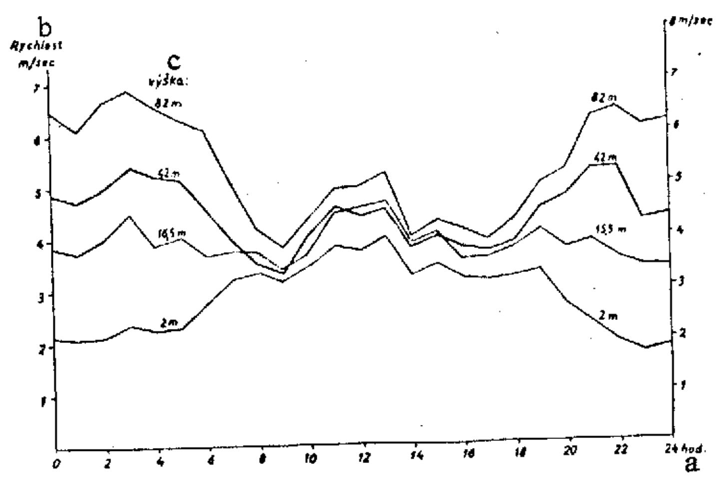

Fig. 7. Wind velocity curves in 24 hours at different altitudes above the terrain.

Key: a. 24 hours
b. Velocity, m/sec
c. Altitude

carried out in our countries, preferably at certain 100-200 kV power transmission line towers and antenna towers (Liblice, Melnik, Brno, Ostrava, Bratislava).

It follows from the wind conditions in our regions and from the general laws which the airstreams at different altitudes above the terrain obey, that favorable conditions for the exploitation of energy exist in our country in the lower Povazka region, especially in the vicinity of Bratislava, in the southern Bohemian belt from Klatovy through Tabor, in the direction of Jihlava and Brno, and less so in the remaining regions. On the ridges and peaks of mountains these conditions must be investigated in greater detail, and we must not forget that other difficulties must be taken into consideration because of the larger equipment, namely the impact force of the wind, the freezing of wind engines and towers, their difficult construction and maintenance, inaccessibility, etc., which may outweigh the advantages of higher elevations. Milešovka, which is one of the wind peaks in our mountains, has an average yearly wind velocity of about 8 m/sec, i.e. it exceeds that of Petřín by 2 m, however the dangerous windstorms and frosts there will certainly be much more adverse than near Prague or in southern Bohemia. The decisive characteristics for the utilization of wind for power engineering purposes are the velocity and steadiness of the stream, the frequency or duration of relatively high velocities and the advantageous location for the installation of engines. To determine these characteristics more reliably in regions that can possibly be considered in our country in accordance with the above-mentioned preliminary data, more accurate measurements and processing of the available meteorological observations for engineering purposes must be carried out.

Generally it can be said that the windiness in our regions is relatively small in comparison with littoral countries and countries with vast and free plains. While the mean yearly velocities in the most windy regions of our Republic that can possibly be considered for the building of relatively large wind power stations hardly exceeds 6-7 m/sec, Berlin and Hamburg for example have average velocities of about 10 m/sec and the average velocities in Denmark, Holland and Ireland are even greater. While the greatest measured velocities in our country are about 35 m/sec, velocities up to 60 m/sec occur on the German coast, up to 75 m/sec in Terst [sic], up to 80 m/sec in North America and 85 m/sec in Japan. If we take into consideration that the power of wind engines increases with the cube of the wind velocity and that it does not depend on the arithmetic average, but on the variable velocity, we see that our conditions are basically less advantageous for taking advantage of the airstreams for power engineering purposes than in the countries that were mentioned. Already the ratio of the cubes of the yearly arithmetic averages of the velocities that were determined in our countries and in Germany gives a utilized power ratio for the same engine which is $10^3:7^3$, i.e. roughly 3:1, and the actual ratio taking into consideration the instantaneous velocities and the elevation diversity and zoning of our regions will be even less advantageous. Winds with a 5-10 m/sec velocity, which are most advantageous for energy use make up, for example in Prague, only 11%, and in East and North Germany, approximately 25%.

Keeping this first sobering bit of information in mind, we continue to study means that can be used to take advantage of airstreams. There are two ways, a direct way in which the wind engine is utilized as the mechanical drive to operate machines, for example pumps, installations in mills, ships, etc., or the indirect method in which the wind engine drives a direct current synchronous or asynchronous generator and the electricity generated in this manner is transferred to the locality where it is needed. The first way has been used for small power outputs also in our country since the earliest times, and we will now examine from the technical and economical standpoint the second method. The book by Eng. Dr. Kaspar entitled Wind Engines and Electricity Generating Stations published in the last year by ESC [abbreviation unknown] will serve well to form an opinion about the suitability of the various means and the possibilities for taking advantage of them. Theoretical and practical information about these questions and also the design documentation and photographs of the engines that are used can be found in it. The book also shows that Czech engineers are not passive in the study of the utilization of wind energy, and that they contributed in addition to theoretical studies various original designs which represent considerable progress in wind engines (Eng. Stastik's wind turbine used in the Sahara desert and in Italy, the combined propeller engine for a large gear moment and automatic folding of the blades of the propeller during a windstorm, designed by Eng. Batrl, the small wind electricity generating stations designed by Eng. Vasak and others).

The wind rotary engines which can utilize airstreams to obtain mechanical or electrical energy are built basically on the principle of taking advantage of the pressure or possibly upward pressure which the wind exerts on the propeller or blades of the engine, or on taking advantage of the Magnus effect which occurs in rapidly rotating smooth cylinders in the stream as a result of the upward pressure on the surface. The original wind engines of windmills that were later perfected and designed with a larger number of folding blades such as the Sörensen, Eklipse, Halladay, Ultra, etc. engines belong to the first type, as well as engines or turbines with the vertical or horizontal axis perpendicular to the direction of the wind, such as the Jackson, Beatson and Rychlovsky engine, the Stastik and Wolf turbines, the Savoni rotor and various bladed rotors. The /483
Madaras, Roscher, Flettner engines and others are another type. The book that was mentioned above by Kaspar describes all these engines and their characteristics. Therefore, they will only be mentioned as necessary to study our problem.

The characteristics of wind engines are very diverse, their power, gear moment, efficiency and high speed differ considerably depending on the type. Relatively large wind electricity generating stations require simple high-speed engines with great powers whose s p e e d s can be controlled and maintained well, which can be controlled automatically as much as possible without service at low maintenance costs. It appears that for the time being these conditions are best satisfied by the simplest high-speed two to three blade propeller with the horizontal axis parllel to the direction of the wind, which turned out to be more economical in a detailed theoretical and experimental study than the multiblade free-wheel wind wheel which seemed to have a greater power and to be more economical. (See the book by Dr. Kaspar that was mentioned above.) With regard to the simplicity of the design, control and regulation during great windstorms, the Stastik turbine and the Savoni rotors have good characteristics, however they are much less efficient, and have large dimensions for greater power outputs. Additional studies and experiments will have to be made to test whether they can be used, and their design will have to be improved so that they can be used on a large scale. They are undoubtedly a good solution for relatively small power outputs and for the direct transfer of mechanical energy to operating engines. Relatively large experimental electricity generating stations with an output of 500-1000 kW have so far been built only by the Americans and by the USSR, using two to three blade propeller engines with a 30-50 m diameter mounted on 30-40 m tall grid towers. News about these electricity generating stations has been published in various publications that are mentioned at the end of the book in the bibliographical references. With regard to the suitability of using a synchronous or asynchronous generator for wind electricity generating stations, Dr. Kaspar published two articles in EO [Electrical Engineering Survey] (1944, p. 145; 1945, p. 60) which are also a good contribution to the solution of this problem.

Given the state of technology of wind engines, it can be assumed that also our country is interested in building wind electricity generating stations with two-blade propeller engines. The striving to obtain the greatest possible output in one station with the smallest possible investment forces us to take advantage of the higher velocities of the wind in the more elevated layers above the ground, however the daily behavior of the velocities at altitudes above 30-40 m limits the usefulness of these altitudes with regard to the consumption curve of the electricity generating stations, since the night outputs are not the same as the day outputs. In accordance with the wind conditions in our regions that were described above and also the results of measurements of the velocity at different altitudes above the terrain which are similar to the measurements made in Germany as far as the character of the daily curves is concerned, we can conclude that the greatest height of the towers that we can utilize when we select the diameter of the propeller must not exceed 30 to 35 m. At this altitude the velocity of the wind will still be sufficiently stable during the entire 24 hours without pronounced night maxima, and we are still able to select the diameter of the propeller up to 50 m to obtain a greater output from one electricity generating station, and take advantage of the greater average velocity than in the layers near the ground in which the effect of the unevennesses in the terrain and other obstacles to a free airflow is more pronounced. To obtain an idea about the outputs and production that can be achieved in our conditions, we will use an approximate formula which is valid for the brake horsepower for propeller engines:

$$N_{bh} = 2 \cdot v^3 \cdot D^2 \cdot 10^{-1}$$

in which we can substitute for v the average velocity in m/sec, for D the diameter of the propeller in m and obtain the output in kW. We obtain the following table for different velocities and diameters:

v m/sec	D = 1	10	20	30	40	50 m
3,5	N_{bh} = 0,009	0,86	3,5	7,7	14	21 kW
5,0	0,025	2,5	10	23	40	62 kW
7,5	0,085	8,5	34	77	136	213 kW
10,0	0,200	20	80	180	320	500 kW
12,5	0,392	39	157	353	628	980 kW
15,0	0,673	67	270	606	1080	1680 kW
20,0	1,600	160	640	1440	2560	4000 kW

Wind velocities above 12.5 stress already too much the structure of the propeller and the regulating equipment of the wind engine, and therefore it is not economical that they be dimensioned for these forces which occur only rarely. Therefore, the propeller blades swivel so that they are not used at higher velocities, or the engine becomes inoperative during windstorms. Hence the brake horsepowers that were calculated for 12.5 m can be considered as the maximum outputs for the given diameter of the propeller This means that for a 50 m diameter, a 1000 kW output is approximately the greatest output of the electricity generating station that can be achieved using a propeller with this diameter and a roughly 30-35 m tall tower that must be used with this diameter. At a wind velocity of 10 m/sec the output of the electricity generating station is only one half this magnitude and at a velocity of 3.5 m/sec (greater than the yearly mean at Karlov), the output is only 21 kW. Let us also estimate the number of kWh that this electricity generating station can produce. To calculate this work, we must know the frequency curve for the velocities throughout the year, or the time during which different velocities occur in our regions. Exact statistical data from meteorological observations along these lines are not available. According to the observations that were described above which were used in the Defant curves in Figs. 1-6 and certain other data, the assumption can be made that the approximate curve for the duration of the velocities in our windiest regions at the altitude 30-35 m above ground that is considered will have approximately the form given by the curve in Fig. 8. If we also enter

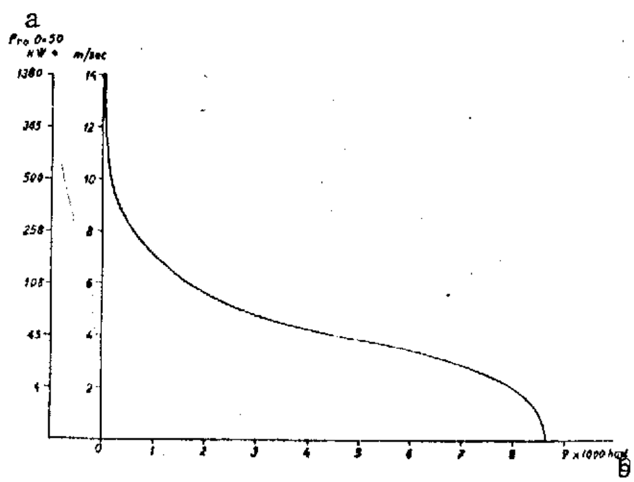

Fig. 8. Curve for the probable duration of wind velocities in windy regions in Czechoslovakia at an altitude of 30 m above ground.

Key: a. For ø = 50
b. Hours

in the table an output scale corresponding to the individual velocities for an engine with a 50 m diameter propeller, we see that only for a short period during the year (approximately 150 hours) the electricity generating station will have an output greater than 500 kW, and for one half of the year (approximately 4300 hours) the output will be in the 20-100 kW range. Taking into consideration the rarity of wind velocities above 10 m, it is not economically feasible to design in our country for a 50 m diameter propeller a generator with an output greater than approximately 500 kW. By an approximate integration of the curve, i.e. a calculation of the sectional areas corresponding to small time intervals, we obtain for the yearly production of the electricity generating station under consideration 700,000 to 800,000 kWh. /484 Hence, if we want to replace, for example, the production of the Ervenice power plant by the production from wind electricity generating stations, we must build approximately 1000 wind electricity generating stations with a 50 m diameter propeller on 30-35 m tall towers. Even then the Ervenice output would not be guaranteed, since the output of wind electricity generating stations fluctuates with the velocity of the wind, as we have seen above, so that it needs, like hydroelectric plants, a steam or battery reserve. The wind electricity generating stations would have to operate in the network with a water storage reservoir with sufficiently large dimensions (for example like the Stechovice reservoir) into which they would pump the water for peak loads. The question of a detailed engineering solution would not present a difficult problem for our industry. Experimental samples of electricity generating stations of the dimensions that have been considered already exist and have been described in the technical literature, the manufacture of towers, wind engines and generators with the required electrical equipment is a task which our factories can undoubtedly solve successfully.

We must still consider the economic aspects of the problem. The expenditures on the purchase of wind engines and generators of the dimensions that have been considered cannot be easily estimated, since we do not have similar samples even on an approximate scale. On the basis of very rough preliminary estimates based on the weights and costs of similar machines and electrical equipment, the estimate can be made that a wind electricity generating station with a 50 m diameter propeller, a generator with a maximum output of 500 kW and a 30-35 m tall tower including accessories will cost at least 3.5 million Czechoslovak crowns. If we estimate the total yearly operating maintenance and amortization expenditures to be approximately 12% of the purchasing price, this will be roughly 420,000 Czechoslovak crowns, i.e. 50-60 hellers/kWh. This price for 1 kWh which is not guaranteed is high, and that obtained from large hydroelectric power plants in our country will be considerably cheaper. If we take into consideration that we need at least 70 t of iron and nonferrous metals for one electricity generating station of the dimensions that were mentioned, which for the time being must be allocated carefully because of their scarcity, we must conclude that in the coming 5-10 years we can hardly begin the construction of wind electricity generating stations, since we still have a great deal of water power that has not been developed which can be built up to obtain greater concentrated outputs, cheaper, using up fewer materials that are important for our entire industrial and agricultural development. For the long-range future, of course, the development of wind engines which may result in a substantial reduction in the price of the designs and also in the availability of reliable meteorological and air engineering data,which for the time being are incomplete and not elaborated sufficiently for technological use,will have to be followed. Joint consultations for this purpose were already held between the research power engineering institutes, the State Planning Institute and the State Meteorological Institute. In addition to power engineering, other branches in our industry and agriculture are interested in the results of this research, since a knowledge of the wind conditions in our regions is also of great importance in aviation, construction, forestry, setting up of windbrakes and other fields. Small standard electricity generating stations with an accumulator battery can still be considered for inaccessible huts in mountains and remote settlements which are far from the general power network, since the supply of electricity over trunk lines to them is difficult and too expensive, which also applies to the transportation of fuels for a household electricity generating station with a differentengine drive. Water pumps driven directly by a wind engine of a modern design are possibly also justified under similar conditions.

So far we do not know at what rate the general practical use of atomic energy will develop and how suitable and economically feasible will be the means by which it will be obtained. Therefore, we must continue to study and perfect the means available for taking advantage of other natural sources, among which the most powerful sources which are continually replenished by nature are water and wind. At the same time we must exert every effort to reduce energy losses during its production and use, since these losses are much greater than the energy used which we are able to channel for our needs. When we are forced to admit that in the production of electricity in thermal power plants we utilize only 15-20% of the energy from the fuel and that in the cooling water of condenser power plants alone we lose one half of the thermal energy of the fuel, we realize that this is actually intolerable power engineering management which we will not correct by trying to improve the efficiency of turbines and boiler houses by several tenths of a percent instead of striving to take advantage of the tremendous amounts of heat that escape with the cooling water into the river or air. To compound this,power plants and their combustion chambers are among the best users of the heat extracted from coal. This management is much worse in railroad locomotives and in certain industrial combustion chambers in which the losses exceed often 90%, which use less than 10% of the heat contained in the fuel. In this field every effort must be made to find new ways to reduce the losses by which we will be able to obtain more energy, gas and heat to satisfy the energy demands without increasing the consumption of fuel. However this will be discussed in another article.

Resume and Conclusion

After a general discussion of the depletion of the world's coal and oil reserves and their value as raw materials for chemical production, alternative energy sources are described and their capacity is estimated in accordance with the data furnished by the physicist Arhenius. Although in the future the main source of energy will probably be atomic fission, it is not yet clear how long it will take before it can be produced economically in this manner and converted into other useful forms (electricity, heat). Therefore, we must continue to use our other natural sources in the best possible way, among which the greatest capacities that are not depleted,is the energy from flowing water and wind.

This study investigates the technical and economic conditions for the utilization of airstreams in the Czechoslovak Republic. The average wind velocities in various regions of the state are determined on the basis of many years of observations made by the State Meteorological Institute. Their frequency and duration, their probable daily and yearly behavior at different altitudes are determined as well as the most windy regions in the Republic and the possibility and extent of taking advantage of airstreams by wind electricity generating stations equipped with engines with a 50 m diameter propeller at a height of 30-35 m are investigated. It has been determined that under our conditions, the maximum output of such electricity generating stations would be approximately 500 kW, the yearly production would be 700,000-800,000 kWh, and that only 1000 such electricity generating stations could replace approximately the output of the Ervenice power plant. The probable cost per kWh produced in wind electricity generating stations has been estimated on the basis of the purchasing costs and the economic consequences of this solution which has no prospect for realization in the coming years have been evaluated.

However, since wind engines are undergoing continuous improvement, it will perhaps be possible to obtain later on a relatively small scale a practical and economical solution. Therefore, it is recommended that the development of wind engines be followed and that research be carried on together with additional meteorological observations and more thorough measurements in which not only power engineering but also aviation, construction engineering, agriculture, forestry and other branches of human activity are interested. A definite decision about the question of constructing wind electricity generating stations in the more remote future can only be made on their basis.